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US Army Corps of Engineers

CRABTREE CREEK QUARRY PIT STRUCTURE

Hydraulic Model Investigation

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by

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Crabtree Creek, located near Raleigh, NC, is prone to flooding in the Crabtree Mall area approximately 4 miles downstream of Umstead State Park. Several retention dams are located upstream of Umstead Park; however, a proposed quarry spillway was preferred over a dry dam upstream of the Crabtree Mall. The quarry pit structure was designed to divert 5,374 cfs of the total 8,420-cfs discharge into the existing quarry located about 2 miles upstream of the Crabtree Mall during a 100-year storm event. A pumping station (not part of this study) was proposed to dewater the quarry after each event.

Several spillway designs were tested in a 1:20-scale model to evaluate hydraulic performance and resulting water levels. The type 3 spillway design, having an 85-ft width in contrast to the original 150-ft width, aligned with the upstream portion of Crabtree Creek, provided the desired flow diversion and distribution. An adjustable weir was

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recommended downstream of the spillway to allow changes in downstream water levels, if it is desired in the future either to increase or decrease the flow diversion into the quarry.

PREFACE

The model investigation reported herein was conducted by personnel of the US Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory from May through August 1989 for the Soil Conservation Service (SCS). The investigation was conducted under the general supervision of Messrs. F. A. Herrmann, Jr., Chief of the Hydraulics Laboratory; R. A. Sager, Assistant Chief of the Hydraulics Laboratory; and G. A. Pickering, Chief of the Hydraulic Structures Division; and under the direct supervision of N. R. Oswalt, Chief of the Spillways and Channels Branch. The tests were conducted by Messrs. W. B. Fenwick and J. Rucker of the Spillways and Channels Branch. This report was prepared by Mr. Fenwick and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

During the course of the investigation, Messrs. Bill Leeming of SCS, Fort Worth, TX; and W. H. Hawkins, S. Biggerstaff, and R. Williams of SCS, Raleigh, NC, visited WES to observe model tests and to discuss these results with WES engineers.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
feet	0.3048	metres

CRABTREE CREEK QUARRY PIT STRUCTURE

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. The Crabtree Creek project, approved by Congress in 1964, is located near Raleigh, NC (Figure 1). Since 1964, 10 floodwater-retarding dams have been built, and the last, which is discussed in this report, is in the planning stage. The last structure, Structure 25, was originally proposed to be a dry dam. This plan met with considerable local opposition due to its storage of floodwaters on Umstead State Park land. It was proposed that a local quarry pit be used to store floodwaters and thereby replace the proposed dry dam for Structure 25. The quarry pit structure was designed to function like the originally planned Structure 25 dam except that it will not raise the level of floodwater in Umstead State Park, which was objectionable in the original plan.

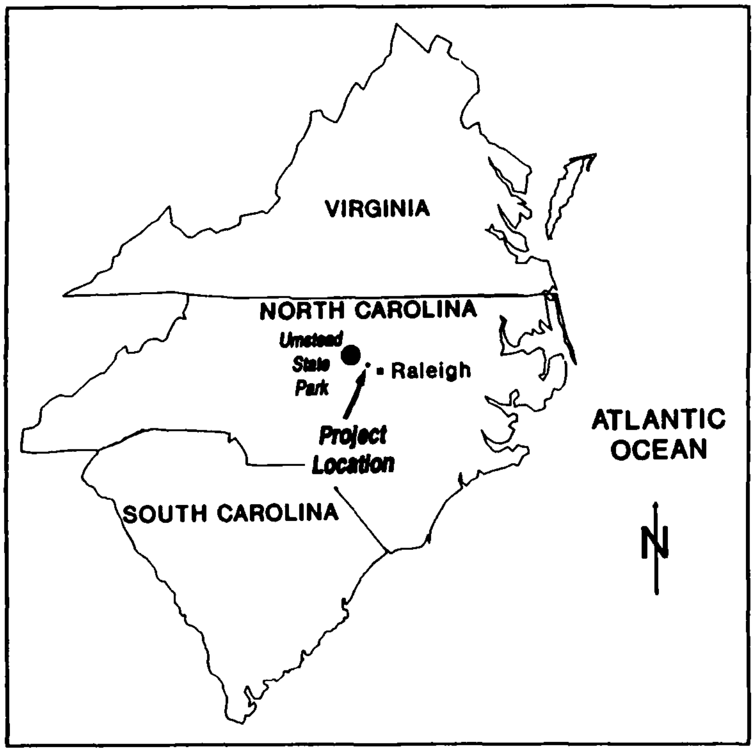

Figure 1. Location map

Purpose of Model Study

2. Model tests of the Crabtree Creek quarry pit structure and the

related weir were conducted to evaluate and improve the hydraulic adequacy of the spillway into the quarry. The proposed weir must be designed to avoid any increase in the water surface in the upstream channel above the spillway.

PART II: THE MODEL

Model Description

3. A 1:20-scale model (Photo 1) reproduced the quarry pit spillway, a 1,000-ft* length of Crabtree Creek upstream from the spillway, a 500-ft length of Crabtree Creek downstream from the spillway, and the channel weir. The entire channel and overbank areas were molded on sand covered with a sand-cement mortar crust and graded to sheet metal templates. The spillway was made of plywood and sheet metal. The weir was made of plywood.

4. Roughness was added to the channel bottom in the form of rocks grouted in place to simulate the prototype roughness. Roughness was increased until the water-surface profile furnished by the Soil Conservation Service (SCS) was reproduced. A vertical slide tailgate was added downstream of the weir so that tailwater could be altered as desired.

Model Appurtenances

5. Flow through the model was recirculated by centrifugal pumps, and discharges were measured with venturi meters. Steel rails set to grade provided reference planes for measuring devices. Water-surface elevations were measured with point gages. Water current directions and flow patterns were determined by injecting dye into the water and sprinkling confetti on the water surface.

Scale Relations

6. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of model data to prototype equivalents are as follows:

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

Characteristic	Dimension*	Scale Relations Model:Prototype
Length	L_r	1:20
Area	$A_r = L_r^2$	1:400
Velocity	$V_r = L_r^{1/2}$	1:4.4721
Discharge	$Q_r = L_r^{5/2}$	1:1,788.84
Volume	$V_r = L_r^3$	1:8,000
Weight	$W_r = L_r^3$	1:8,000
Time	$T_r = L_r^{1/2}$	1:4.4721

* Dimensions are in te: of length.

Model measurements of discharge, water-surface elevations, and velocities can be transferred quantitatively to prototype equivalents by means of the scale relations.

PART III: TESTS AND RESULTS

Type 1 Spillway

7. The quarry spillway as originally built in the model was referred to as the type 1 design and is shown in Plate 1 and Photo 2. An overview of the model is shown in Plate 2 and Photo 1. The orientation and location of the type 1 spillway are shown in Plate 2.

8. During initial tests with the type 1 spillway design, the model was calibrated by adding roughness to the channel until the SCS water-surface profile was approximated for the design discharge. The entrance to the spillway was blocked off during these calibration tests. The SCS water-surface profile and the model profile are shown in Plate 3 with a discharge of 8,420 cfs (100-year storm). Also shown in Plate 3 is a water-surface profile for a discharge of 3,046 cfs, which is that portion of the 100-year flood that remains in Crabtree Creek after 5,374 cfs of the total 8,420 cfs is diverted into the quarry spillway. These tests were conducted without a controlled tailwater downstream of the weir.

9. During tests with the type 1 quarry spillway open, a discharge of 1,400 cfs was determined to be the maximum discharge that remained within Crabtree Creek before flow over the spillway occurred. A tailwater elevation of 232* just downstream of the weir was established with the model tailgate. A water-surface profile for this condition is provided in Plate 4. Flow conditions with the 1,400-cfs discharge and tailwater el 232 are shown in Photo 2.

10. Water-surface profiles with discharges of 3,046 and 8,420 cfs (type 1 design) are shown in Photos 3 and 4, respectively. Photo 5 is a close-up of the spillway at a discharge of 8,420 cfs. It can be seen in this photograph that sizeable standing waves and severe eddies were present in the type 1 design. It was apparent that these conditions were caused by the direction of flow being nearly perpendicular to the spillway alignment.

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* All elevations (el) and stages cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

Type 2 Spillway

11. Using sandbags placed as shown in Plate 5, the downstream area of the spillway opening was closed off and the spillway width reduced to 90 ft (type 2 design). The type 2 design resulted in significantly improved flow conditions for the full range of discharges up to the 100-year flow of 8,420 cfs. It also reduced the water-surface elevation from 246.4 to 244.0 at a location 1,000 ft upstream of the weir. This reduction is significant because in addition to the primary purpose of flood reduction downstream in the Crabtree Mall area, the quarry spillway is designed to keep from raising the upstream water surface near Umstead Park. The type 2 design quarry spillway was aligned similar to the original type 1 design. Several SCS engineers observed the type 2 design during a visit to the US Army Engineer Waterways Experiment Station (WES).

Type 3 Spillway

12. It was apparent that flow conditions could be greatly improved and rock excavation quantities significantly reduced by reorienting the spillway to be more parallel to incoming flow. The quarry spillway was redesigned and reoriented based upon discussions between SCS and WES engineers at WES on 19 and 20 June 1989. The type 3 (recommended) design resulted from these discussions and additional model testing. The type 3 design (Plate 2) was constructed with a moveable right wall so that the desired flow division of 5,374 cfs into the quarry and 3,046 cfs continuing downstream in Crabtree Creek could be achieved. This desired flow division occurred at a structure bottom width of 85 ft and 1H on 4V sidewalls (Photo 6).

13. A water-surface profile of Crabtree Creek (type 3 design) with the discharge at 8,420 cfs was measured with the tailgate at the same setting as used in the type 1 design (Plate 6). Note that 1,000 ft upstream of the weir, the water surface was lower than with the type 1 design (Plate 3). Obviously, the streamlined structure (type 3 design) caused less backwater effect than the type 1 design. With the tailgate removed, stop logs 4.25 ft high were required in the weir to maintain the desired water-surface elevation of 239 just upstream of the weir. With no tailgate or stop logs, 4,360 cfs went into the quarry and 4,060 cfs passed on downstream.

14. Velocities were measured at seven locations (Table 1) with a discharge of 8,420 cfs. The type 3 design spillway was diverting 5,374 cfs into the quarry with 3,046 cfs passing downstream.

15. A water-surface profile in Crabtree Creek was measured with a discharge of 1,400 cfs, the tailgate removed, and stop logs 3.25 ft high added to the weir so that the water surface was at the spillway crest. This profile is shown in Plate 6. Photo 7 shows the weir and Photo 8 shows the structure with 3.25 ft of stop logs added and a discharge of 1,400 cfs.

PART IV: SUMMARY

16. In summary, the type 3 design quarry spillway (Plate 7), having an 85-ft width in contrast to the original 150-ft width, aligned with the upstream portion of Crabtree Creek, provided the desired flow diversion and distribution. During a 100-year storm event, the type 3 design spillway will divert approximately 5,370 cfs of the total 8,420-cfs flow in Crabtree Creek into the quarry with 3,050 cfs to continue flowing downstream toward the Crabtree Mall. An adjustable weir is recommended for the prototype to allow changes in downstream water levels, if it is desired in the future either to increase or decrease the flow diversion into the quarry.

Table 1

Prototype Velocities

Type 3 Design

Location from Weir	10 ft from Left Bank	Center of Channel	10 ft from Right Bank
20 ft upstream	7.2	3.6	0.9
20 ft downstream	8.0	7.6	3.1
40 ft downstream	2.2	7.6	3.1
60 ft downstream	5.8	6.7	4.0
80 ft downstream	5.8	6.7	0.9
120 ft downstream	5.8	5.4	1.3
160 ft downstream	5.4	4.5	0.9

Note: Total discharge 8,420 cfs, 3,046 cfs passing downstream where velocities were measured and 5,374 cfs into quarry.
Velocities measured at 3 ft below water surface in feet per second.

Photo 1. General view of 1:20-scale model looking downstream

Photo 2. Weir and spillway structure (type 1); discharge 1,400 cfs; tailgate set to water-surface el 232 just downstream of weir

Photo 3. Weir and spillway structure (type 1); discharge 3,046 cfs; tailgate set to water-surface el 232 just downstream of weir

Photo 4. Weir and spillway structure (type 1); discharge 8,420 cfs; tailgate set to water-surface el 238 just upstream of weir

Photo 5. Spillway structure (type 1); discharge 8,420 cfs; tailgate set to read just upstream of weir

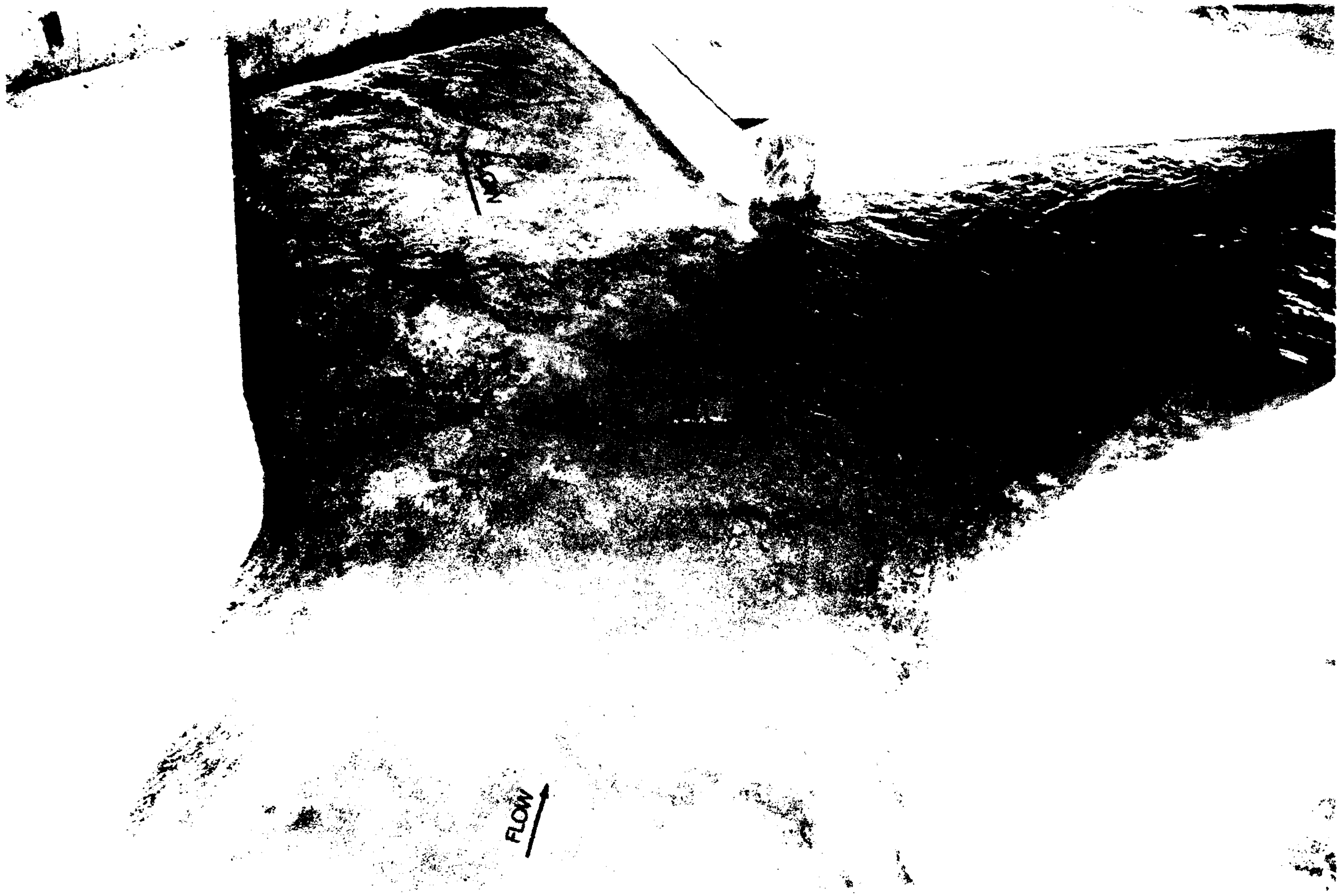
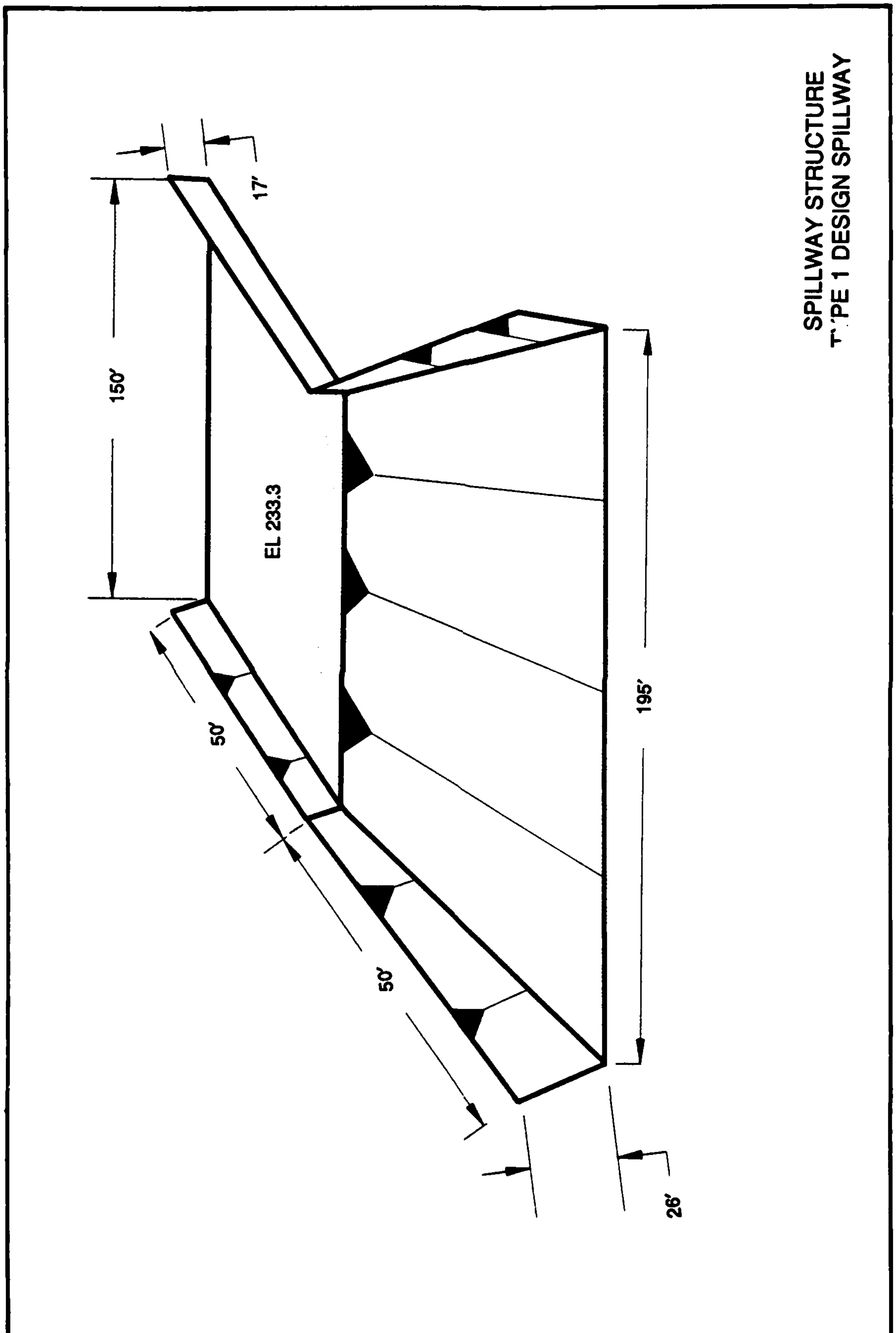


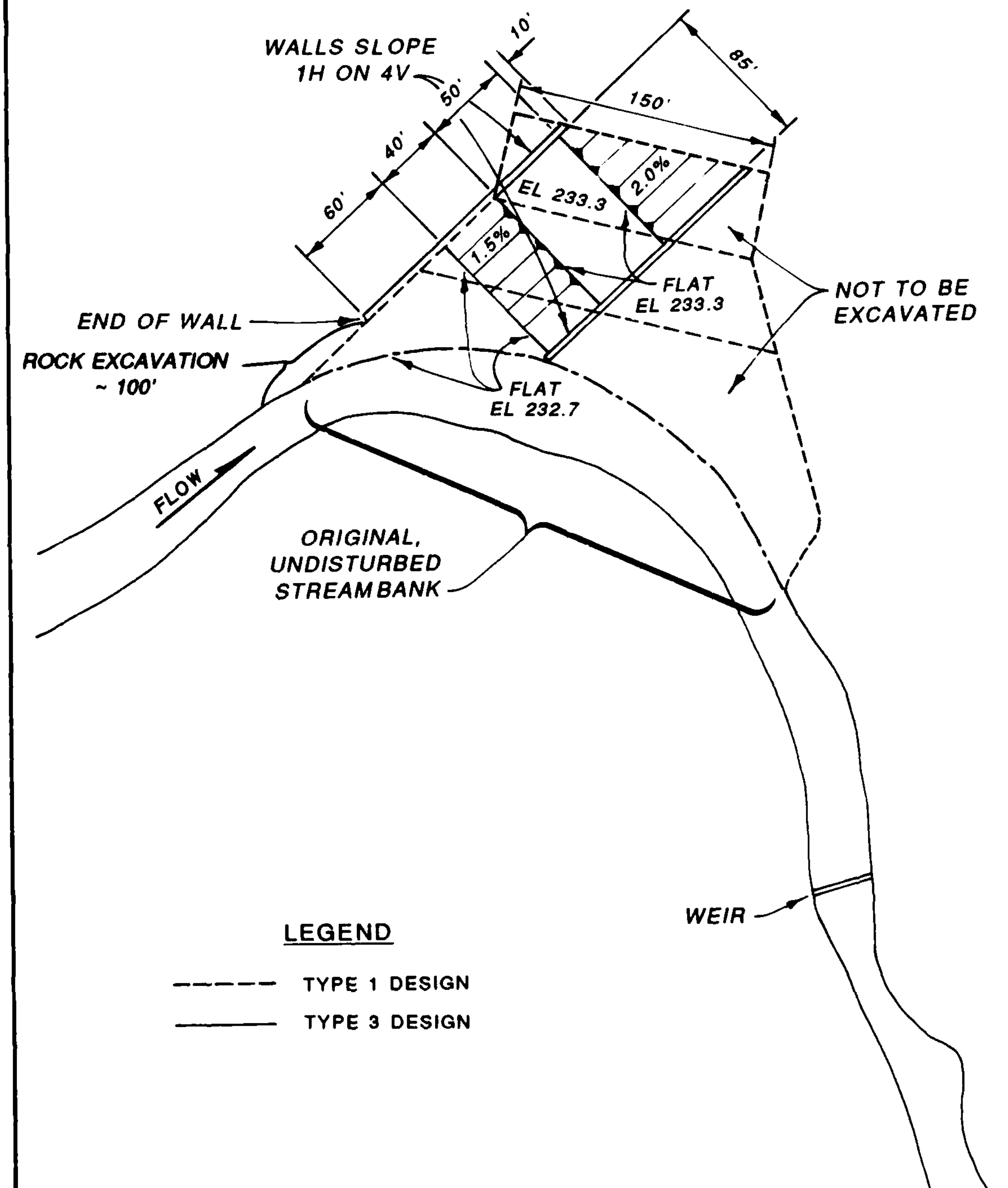
Photo 6. View of type 3 structure; no stop logs; discharge 8,420 cfs; tailgate at proper setting

Photo 7. Weir with 3.25 ft of stop logs; discharge 1,400 cfs; no tailwater

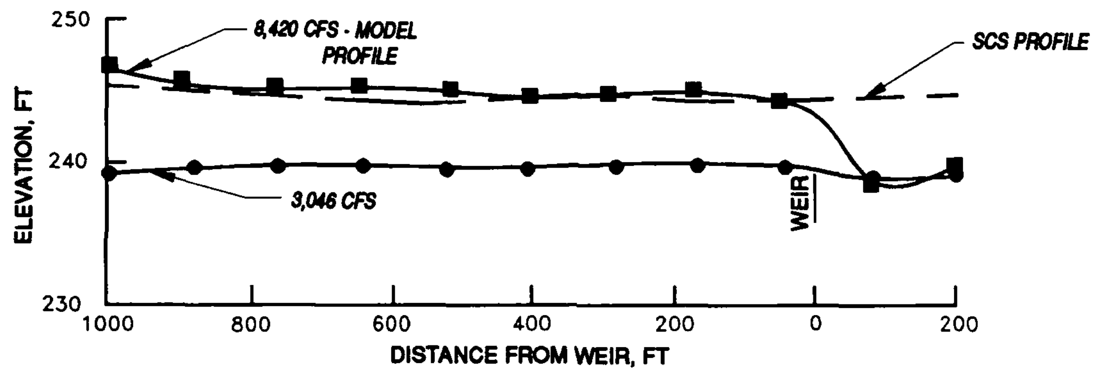
Photo 8. View of type 3 structure; discharge 1,400 cfs; 3.25 ft of stop logs in weir



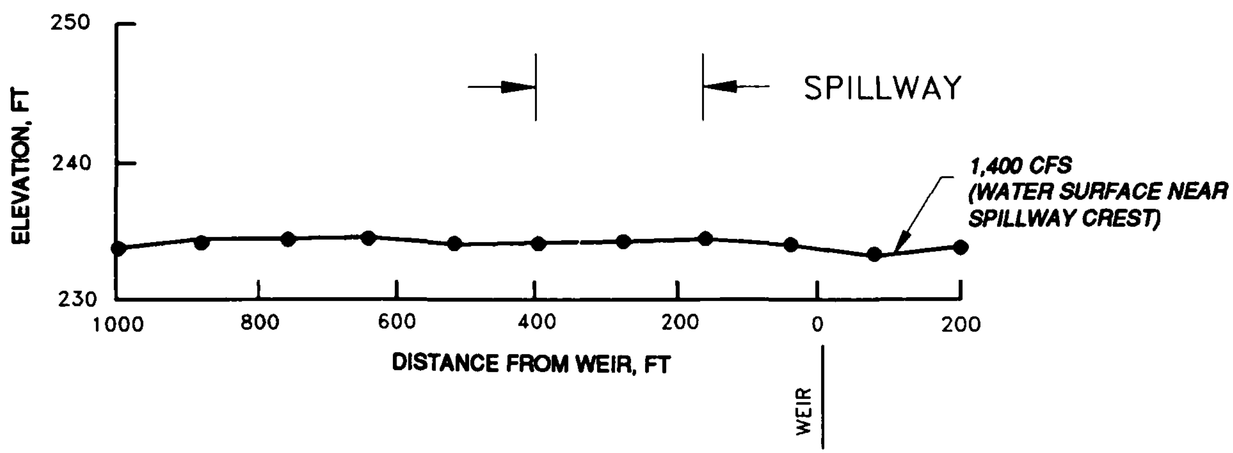
SPILLWAY STRUCTURE
TYPE 1 DESIGN SPILLWAY



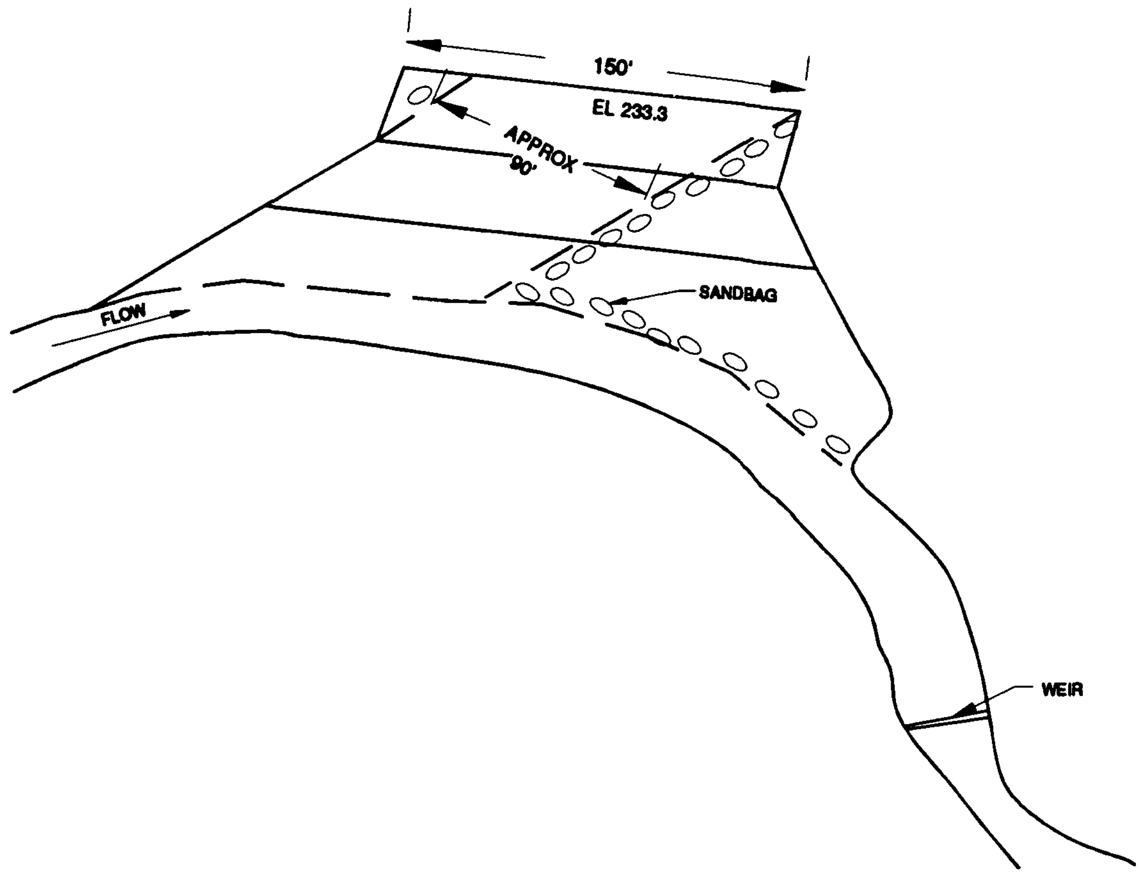
SPILLWAY LAYOUT



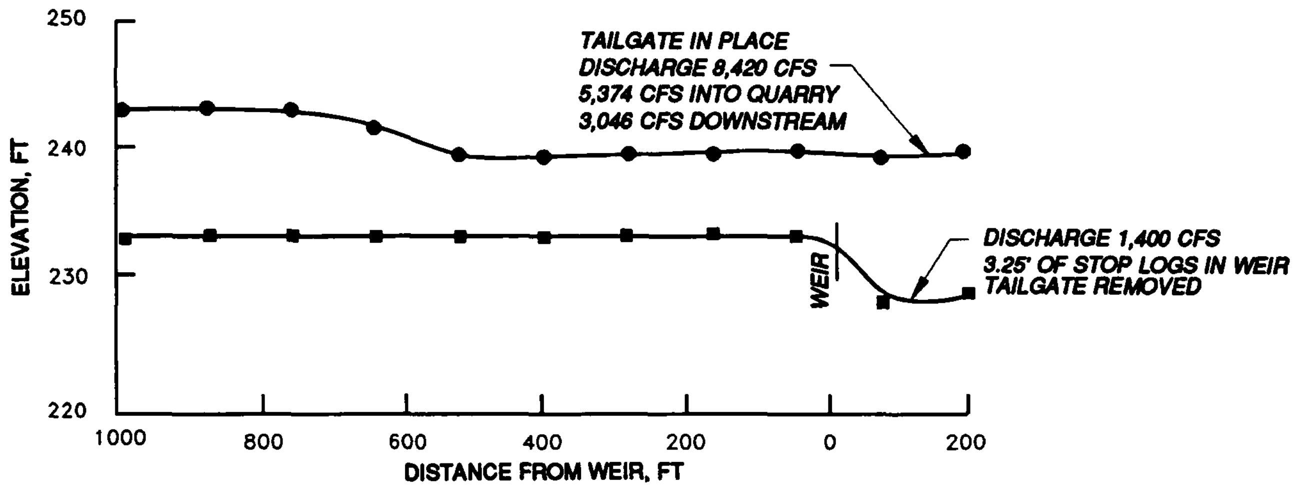
WATER-SURFACE ELEVATIONS
WEIR IN PLACE
SPILLWAY BLOCKED



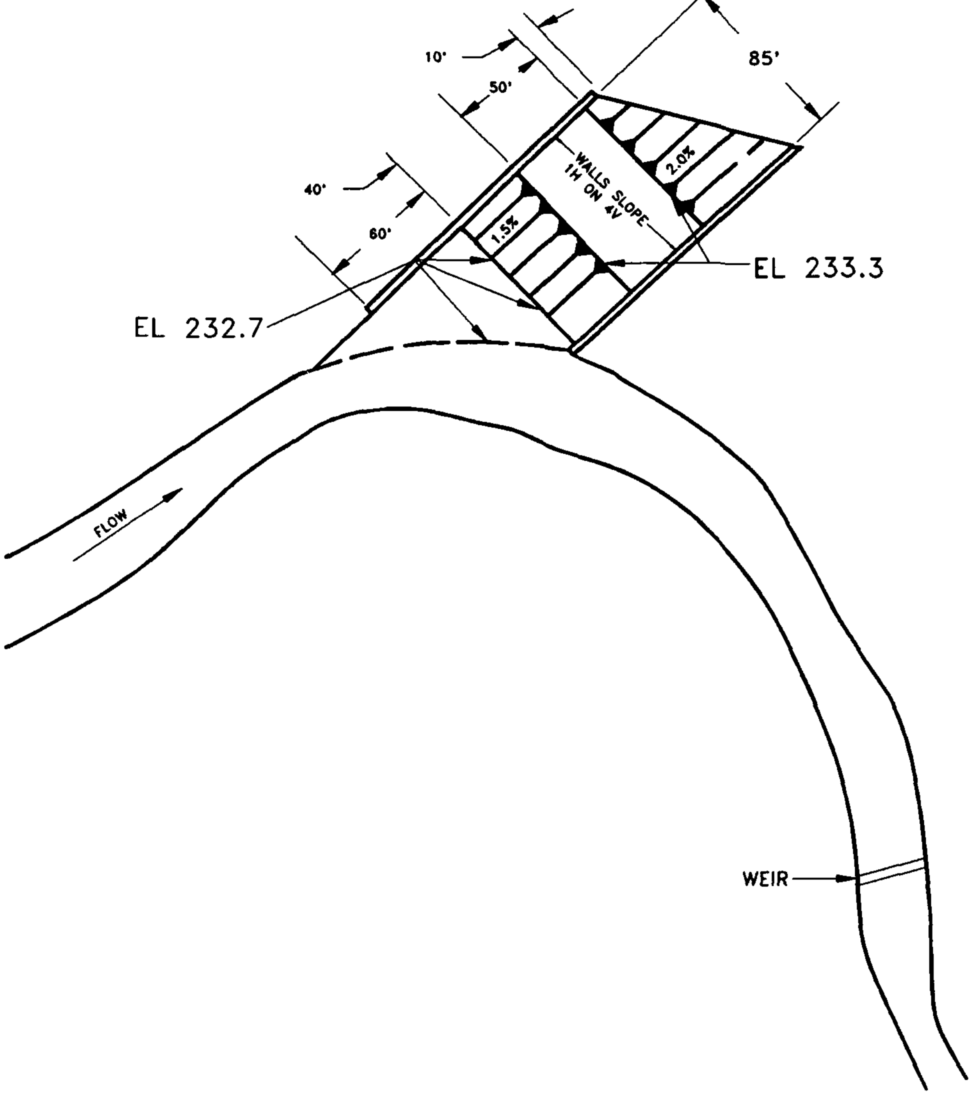
WATER-SURFACE ELEVATIONS
ORIGINAL DESIGN (TYPE 1) SPILLWAY



TYPE 2 DESIGN SPILLWAY



WATER-SURFACE ELEVATIONS
TYPE 3 DESIGN SPILLWAY



TYPE 3 DESIGN SPILLWAY